STREAMLINING COLOUR COMMUNICATION

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Rezumat. *Tehnologia grafică este un beneficiar direct al progresului și invențiilor în domeniile ingineriei, tehnologiei informației, fizicii și chimiei, în timp ce dinamica acestei revoluții industriale promovează nișe noi și remodelează, redefinește și reinvestește aplicațiile de imprimare existente. Standardizarea impune o nouă modelare, mai bună, a proceselor tehnologice grafice, rezultând un flux de lucru mai automatizat și mai bine integrat, simplificând procesul, reducând în același timp rata de eroare și necesitatea intervenției operatorului. Această provocare conduce la cercetarea și dezvoltarea metodelor de testare și a specificațiilor care vizează fluxul tipic de producție tipografică de la originalul furnizat la produselor finite.*

Abstract. *Graphic Technology is a direct beneficiary of progress and advancements into the fields of engineering, information technology, physics and chemistry, while the dynamic of this industrial revolution adds new niches and reshapes, redefines and reinvents existing printing applications. The standardization is pushing for better and new modelling of graphic technology processes resulting into more automated and better integrated workflow streamlining the process while reduces the error rate and the need for operator intervention. This challenge is leading to research and development of test methods and specifications aimed at the typical printing production workflow from the original provided to the finished products.*

Keywords: graphic technology, printing, matching colour

1. Introduction

In every industrial domain, the consistent relation between the original specification and technological process result indicates a high level of quality. A fondamental requirement of this relation is the usage of a meaningful and significant set of applicable norms in such a manner as to standardize the respective process. It must be a clear distinction between the fulfillment of the original specification and the necessary steps that the production process shall follow to achieve it. The first statement refers to what is called Quality Assurance and in graphic technology this is practically "what we see", the aim being here to

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evaluate the planned and systematic actions needed to provide adequate confidence that a reproduction is fulfilling the requirements for quality [1]. The latter statement refers to what is called Process Control, a general concept used to describe the framework meant to ensure the functionality, predictability and repeatability of a production system.

The challenges graphic technology is facing today pushes the domain to find the right balance between the quality and the commercial requirements of the print buyers that translates into productivity and efficiency requirements for print service providers. When producing a color reproduction using a printing technology, it is important that the parties responsible for data creation, color separation, proofing and printing operations have previously agreed on a minimum set of parameters that define visual characteristics and other technical properties of the planned print product [2]. Based on the fact that pleasant colorful reproduction is not enough anymore, markets requirements that defines the need of printer's adaptability to expectations are guided by the motto "*Printing the Expected*" across production locations using various printing technologies, substrate and production batches, even to different viewing environments.

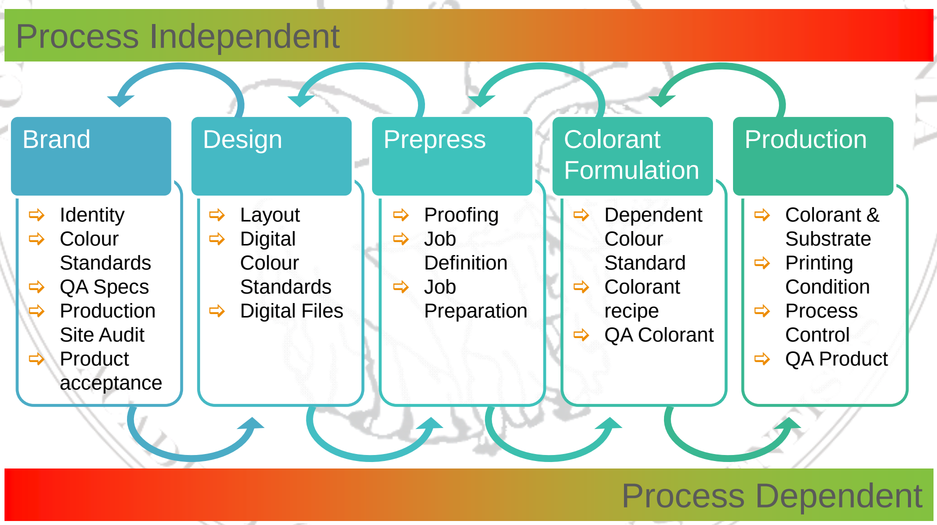

Fig. 1. Up and down the stream everything is interconnected.

To increase the predictability of such graphic technology workflows from the original provided to the finished products, many of the steps involved needs to be unambiguously and properly defined so that any (intermediary or final) states of the product will have a clear input and output relation that can be shaped while the product can be evaluated with applicable metrics in respect to quality assurance and process control protocols (Fig. 1).

2. Requirements and recommendations

2.1. Colour standards

Out of context, color communication by name is ambiguous and does not define the expectation of color reproduction, while the latter is by far more than the color name. Even when the source of the color name or its code is a color library like one of the widely-used Pantone libraries, additional steps need to be taken to ensure its adequate reproduction.

In general, a master color is process independent being disconnected from the underlying printing technology. Even its name or code may point to a different color standard when related to color library version (e.g. 364 C, Pantone vs. Pantone+ libraries). The natural evolution of such libraries means that several revisions may be published over the years and both the specifier and the recipient shall agree on the right version of the library. Out of date libraries are still one of the major scorers on the color miscommunication scale.

Due to the differences of printing combinations (substrate/printing process) used for color reproduction, a master color standard may be also difficult to relate properly to defined specifications and expectations.

When the production is spread over various such combinations, the resulting production variation is subject to interpretation. The solution in such cases is to reduce production variation based upon targeting a dependent color standard with an aim point that is realistic, achievable and explicit and has a known relationship to the master color standard (Fig. 2).

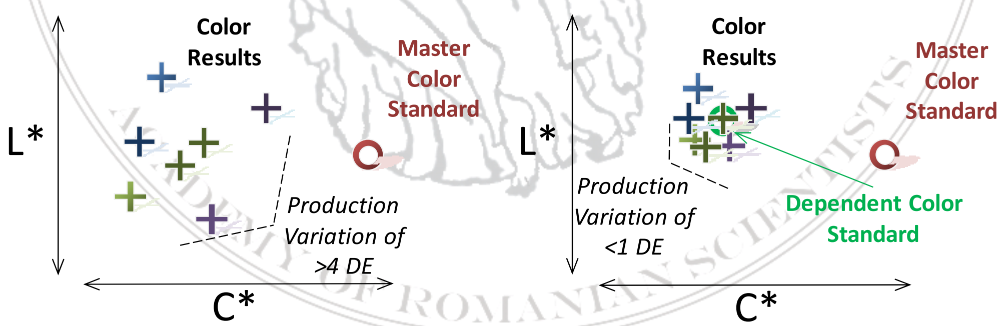

Fig. 2. Master and dependent color standards.

Such an approach is used by Pantone to provide dependent standards through their Pantone Live [3] cloud based service for enabled applications adding more than 20 dependent standard libraries (Fig. 3) for the most used printing combinations for packing printing applications.

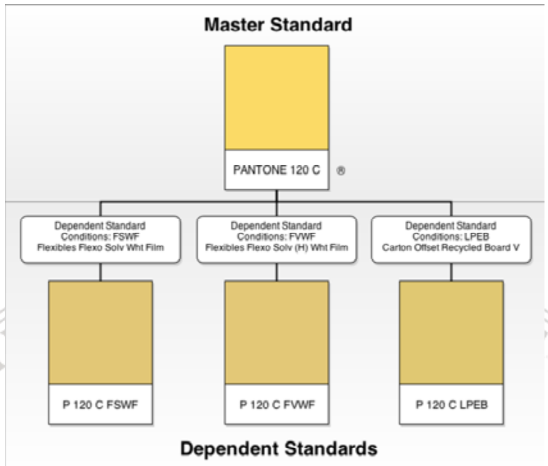

Fig. 3. Pantone Live Master/Dependent standards structure.

Another form of color standards are the physical master color standards (Fig. 4) that are usually provided for the side by side comparison of the reproductions under standard viewing environments as presented in 2.5. Three to ten steps variations into different directions of CIELAB color space are provided as a visual markup for observers responsible for the quality assurance protocols. Color Tolerance Sets are ideal for multi-component products manufactured by multiple suppliers in different locations using a variety of processes, printing included. Besides specifying the color tolerance, or range of acceptable color deviations, by which the finished product will be evaluated, gloss levels and specialty metallic or pearlescent color match and textured finishes may be also incorporated as part of the full product appearance.

Fig. 4. Munsell 3-Step Color Tolerance Set.

While the purpose of these color tolerance cards is very clear, in some instances a color card or master sample is the only available meaning to relate to the color standard. As such, the metamorphosis of master color from the physical form to its digital spectral finger print is entirely dependent on the relevant set of measurement parameters that are stipulated for the use case of process control and quality assurance metrological protocol as presented in 2.4.

2.2. C×F/X – Color data exchange format

The C×F3 represents the universal hub of color data exchange transporting and containing all physical aspects and specific information of the color. As a standardized version of C×F3 for data exchange, ISO17972-1 [4] defines the C×F/X exchange format for color and process control data (and the associated metadata necessary for its proper interpretation) in electronic form. Where necessary it also defines additional requirements for a valid C×F/X file. Based on XML, all CxF3 and C×F/X documents also support the exchange of data outside of the graphic technology workflow and can support future standards with an extensible architecture using standard XML Names and Metadata tags which can be used with standard XML tools and pass XML validation. As such it opens a multidirectional bridge of color communication between various industries and their specific applications.

A more specific version of it is introduced by ISO 17972-4 [5] that defines an exchange format for spectral measurement data of inks to provide a means to characterize spot color inks to allow reliable printing and proofing of products that have been designed using these inks. Only isotropic (paper-like) substrates are within the scope of the standard which is limited to application areas where the same ink and substrate combination that has been characterized is used when printing. As presented in Table 1, the specification defines three conformance levels identified as C×F/X-4, C×F/X-4a and C×F/X-4b.

Table 1. C×F/X-4 Conformance levels

No.	*Type of measurement*	*C×F/X-4 Complete Characterization*	*C×F/X-4a Single Background Characterization*	*C×F/X-4b Single Patch Characterization*
1.	Solid ink printed on substrate	Required	Required	Required
2.	Tints of ink printed on substrate	3 minimum, 11 recommended	3 minimum, 11 recommended	No requirement
3.	Tints of ink printed on black background	3 minimum	No requirement	No requirement

Measurement data in a conforming C×F/X-4 file should be taken from a spot ink characterization chart as shown in Fig. 5. The measurement data provides the characteristic color response for the combination of ink and substrate. A less known fact is that the actual C×F/X-4 data may be incorporated inside a PDF/X-4 file format allowing basically a full exchange not only of printing data, but also of the color data (Fig. 6). The embedded SpectralData C×F/X container is coded inside the PDF/X-4 format as Spectral Data Dictionary and together with printing order defined by the MixingHints it fully communicating the process related usage of the color data and their relation to the actual printing condition main parameters.

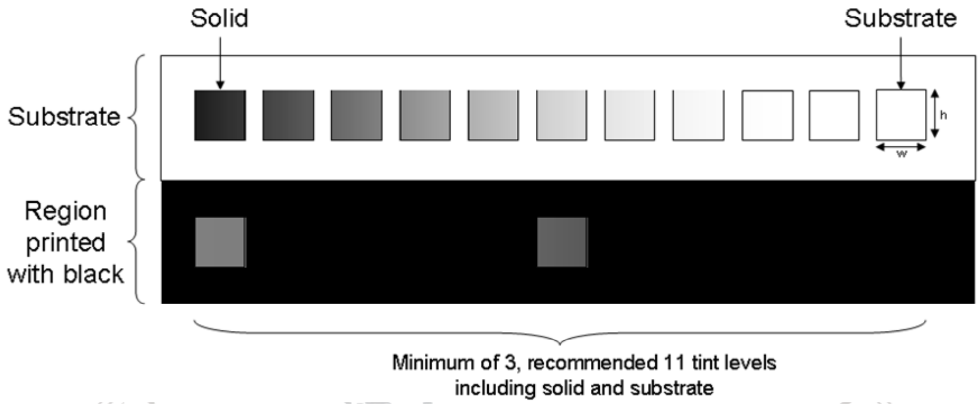

Fig. 5. Characterization chart preparation [5].

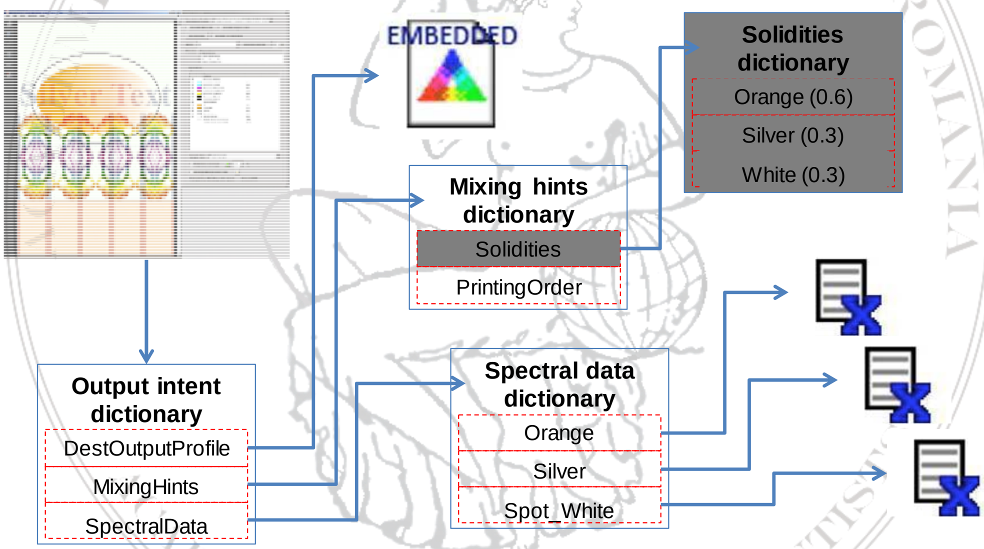

Fig. 6. Spot color ink proofing and printing using PDF/X-4 and C×F/X-4.

2.3. Calculation of intermediate tones

Spot colors are also used mostly as solids, compared to tone values or overprints with other colors as in traditional four color process printing.

But such cases are mostly confined to traditional commercial and industrial applications while packaging and other niche applications are also using spot color tones and the main question here based on "measure as we see" principle, is how to calculate a 50% tone value of a spot color so that it will be perceived visually as half of the spot color full tone value. The typical use cases are (Fig. 7):

- use case A: measurement of intermediate tones needed to provide the definition of color for printing process control and for accurate color proofing – this would ideally be provided as C×F/X-4;
- use case B: color estimate for intermediate tones needed to provide the definition of color as swatch books available in graphic applications, e.g. Adobe Creative Cloud applications and PDF/X-4 (and future versions) compliant soft-proofing environments.

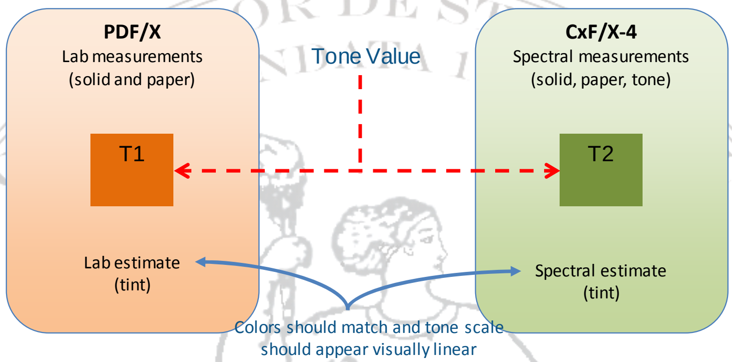

Fig. 7. Spot color tone value metric objectives.

Interconnecting the two use cases with a not too complex to implement formula based on both spectral (use cases A) and CIELAB (use cases B) color data was possible by the research and effort of the SCHMOO (Spot Color Halftone Metric Optimization Organization) project initiated by ISO TC 130 experts. Around 10 different methods of estimation of intermediate tones were evaluated (Fig. 8) to derive a perceptual uniform way to calculate tone values for spot colours (between substrate and colour) varying from densitometric one like Murray Davies formula to spectral one like ISO Spectral Density.

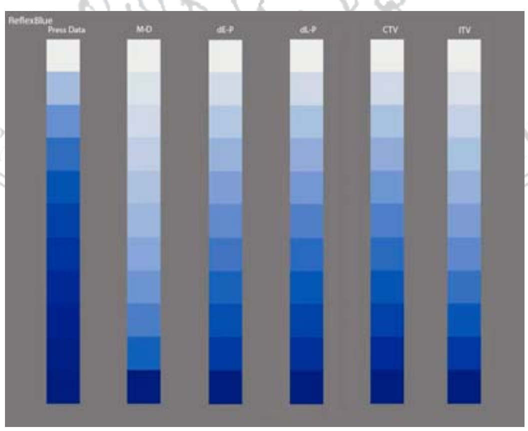

Fig. 8. The perceptual representation of different methods for Pantone Reflex Blue tones.

The problem is easy to spot when looking at the equivalent numerical calculations results of these formulas pointing out to the discrepancy between numbers and perception (Fig. 9), also the necessity to develop a more suited formula for the task.

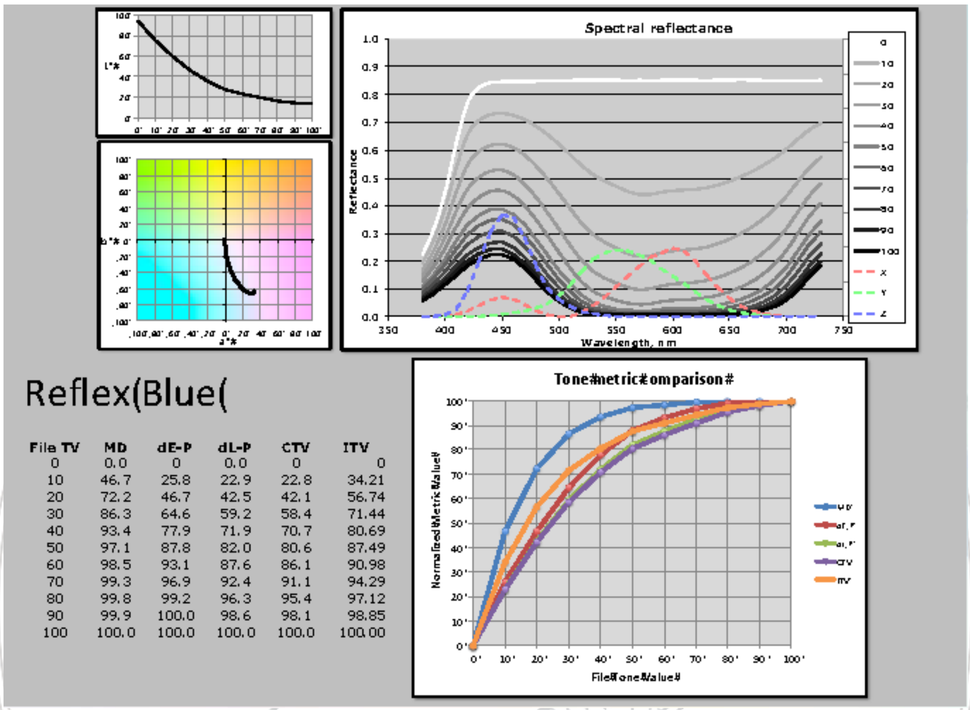

Fig. 9. The calculation of different methods for Pantone Reflex Blue tones.

The new formula named SCTV (Spot Color Tone Value) is currently under development and testing under ISO/CD 20654 [6] name and is expected that as soon it will be published as ISO standard to be adopted and implemented by both measurement device manufacturers and software developers.

2.4. Colour measurement

The color measurements and calculation of tristimulus values for reflective and transmissive samples shall be made in accordance with ISO 13655 [7], while measurement conditions should be M1, white backing. In graphic technology, the measurements are restricted to production print substrates that allows a meaningful interpretation of ISO 13655-compatible measuring instrument readings for front viewing conditions corresponding to reflectance response (0°:45° or 45°:0° geometry) and transmittance response (d:0° geometry). This is consistent with isotropic (paper-like) substrates based printing combinations. When the used colorant exhibits fluorescent behavior, a 0 to 200% photometric range device is required.

Specialty metallic, pearlescent and textured finishes substrates/inks combinations requires d:8° geometry measurement, typically SPI/SCI, to result in meaningful measurements based on the "measure as we see" principle. Such a setup that is no in the scope of ISO 13655 is needed by the practical requirements. With cross-industrial applications involving graphic technology getting pace, the usage of sphere optics geometry is becoming more common. When choosing a printing substrate as part of a printing combination intended to match a color standard, other measurable aspects than color itself should be considered like opacity, fluorescence and gloss. The choice of measuring backings as defined by ISO 13655 (white and black) and their influence on the color measurements are important when it comes to lower opacity or perforated samples.

When measuring half-tones, screen ruling is another factor that should be considered when selecting the instrument sampling aperture. If the area measured is made too small, the measurements become erratic and depend on the number of half-tone dots that happen to be measured. As such a 2 mm aperture is required for screens of 52 lines / cm and up, while 4 mm is required for 26 lines and up. By analogy to the screen ruling factor considered when selecting the instrument sampling aperture to reduce uncertainty of the single measurement, it is highly recommended to use appropriate large aperture sizes that allows consistent measurements. Scanning instruments that facilitate a virtual averaging are providing also such means [7].

2.5. Viewing environment

Matching measurements for test prints need to be consistent with the visual judgement. This can reasonably be expected by using viewing cabinets complying with viewing condition P1 of ISO 3664 [8] using the CIE D50 illuminant. Based on metamerism and color inconstancy indexes check requirements, additional viewing conditions (CIE illuminats A, F11 – TL84, D65, etc.) may be used to appraise or compare test samples. As a rule, the best viewing condition for the visual assessment of color is that in which it will be finally seen.

The Metamerism-Index (MI) will show the probability that two samples will show the same color difference under two different illuminants (represented by the first and second illuminant):

- if MI is low the color difference between the sample pair is the same for both illuminants. It does not mean that the two samples match, it means, that the two samples show the same difference for both illuminants;
- if MI is high there is a different color difference between the two samples at two different illuminants. The samples might match under one illuminant, but not under the second. Or the sample 1 might be red under illuminant 1 and green under illuminant 2.

Color Inconsistency indicates a color change in the sample (without any reference to the standard) under different illuminants. The Color Inconsistency-Index (CI) is a new index for which experimental data has not been gathered and therefore no hard and fast rules on acceptable tolerances have been established.

2.6. Computation of the CIEDE2000 total colour difference

When evaluating two colors side-by-side (e.g. a standard and a sample), the distance between them can be measured based on the "measure as we see" principle using CIEDE2000 total color difference (ΔE^*_{00}) as described in CIE Publication 15:2004 and CIE Publication 142 [9]. The CIEDE2000 total color difference formula corrects for the non-uniformity of the CIELAB color space for small color differences under reference conditions. Improvements to the calculation of total color difference for industrial color difference evaluation are made through corrections for the effects of lightness dependence, chroma dependence, hue dependence and hue chroma interaction on perceived color difference.

Table 2. ΔE^*_{00} Color Standard Pass/Fail tolerance as specified by several typical uses cases

	Cross-industrial applications	*Packing and Commercial applications*	*ISO 12647-7 : 2016* [10]	*Fogra PSD* [1] *Level A*	*Fogra PSD* [1] *Level B*	*Fogra PSD* [1] *Level C*
Deviation from standard	$\Delta E^*_{00} \leq 1{,}0$	$\Delta E^*_{00} \leq 2{,}5$	$\Delta E^*_{00} \leq 2{,}5$	$\Delta E^*_{00} \leq 2{,}5$	$\Delta E^*_{00} \leq 3{,}5$	$\Delta E^*_{00} \leq 5{,}5$
Production variation	-	$\Delta E^*_{00} < 1{,}5$	-	-	-	-

A Pass/Fail decision based on CIEDE2000 metric is highly dependent on the application use case as presented in **Error! Reference source not found.**.

3. Practical use care

A typical example of cross-industrial application is the blend between textile and graphic industries. In such a scenario, physical samples of textile production batches are provided to the site creating the designs using a creative application and printing it using a digital printing inkjet system and its associated printing conditions. The foundation of the use case is unambiguous communication of color specification and tight measurement protocol. The next step is the accurate characterization of the output printing condition that will be used to reproduce the color standards. The suitability of the printing combination choice is determined by the in-gamut color capability and the subsequent tweaking of the output mapping (media dependent CMYK + recipe) for the best match (smallest achievable ΔE^*_{00} inside the Pass tolerance) color reproduction for the respective printing condition. The printing condition should be based on a combination of substrate/colorant that is having a similar appearance (color, fluorescence, gloss and texture) as the provided color standard.

The color data of the color standards provided via CxF3 data format is most of the time related to the choice of d:8° sphere optic geometry measurement protocol/device specific to textile industry.

Even if such a device is available in the location, due to normal limitations of inter-instrument/-model/-geometry measurement agreements (Fig. 10), it is highly recommended to re-master in-house the physical color standards using the same measurement protocol/device corresponding to the calibration/characterization process control operation to avoid a startup inconsistency of over 2,0 ΔE^*_{00}.

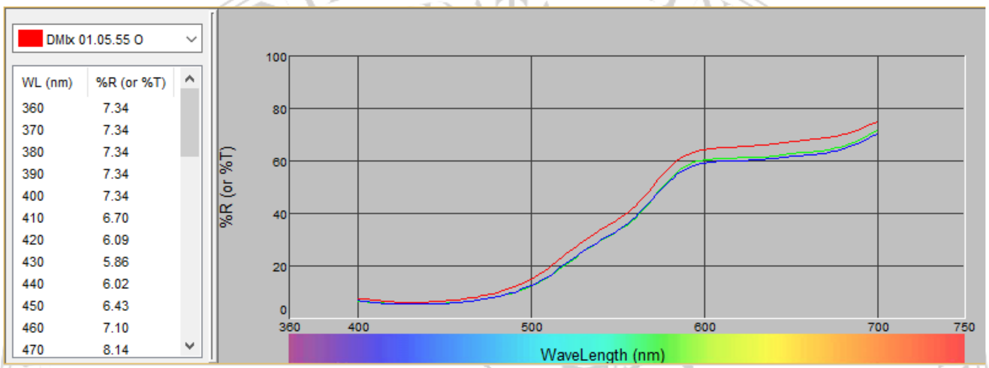

Fig. 10. The color standard differences between provided and actual measurements using both 45°:0° and d:8° geometries.

Not only the measurement choice will impact the outcome, but also the colorimetrical calculations since the reference system is different between the two industries, CIE D50/2° (graphic) and CIE D65/10° (textile).

From the in-house measured spectra of the color standards, the correct names and CIELAB values can be used to build a swatch book for the design application and a color library for the printing workflow.

For color management activities, the printing combination that will be used for the reproduction of color standards shall be accurately transformed into a fully characterized printing condition using the necessary adjustment, calibration and characterization operations employed in the typical digital printing process control.

Once this step is finished, the accuracy of the colour standard reproduction should be checked according to the Pass/Fail protocol.

As with the case with current CIELAB based ICC based color management workflows, the global accuracy may be appropriate for the general use case application, but when tested on specific spot color reproduction, it may exhibit higher than desired ΔE^*_{00} reproduction tolerance (Fig. 11).

Fig. 11. Side-by-side view of master color standards and digital prints reproductions under reference conditions.

Due to the colorimetrical color match as opposed to spectral match, the result may be not fully adequate for viewing conditions other than the standard one defined by ISO 3664.

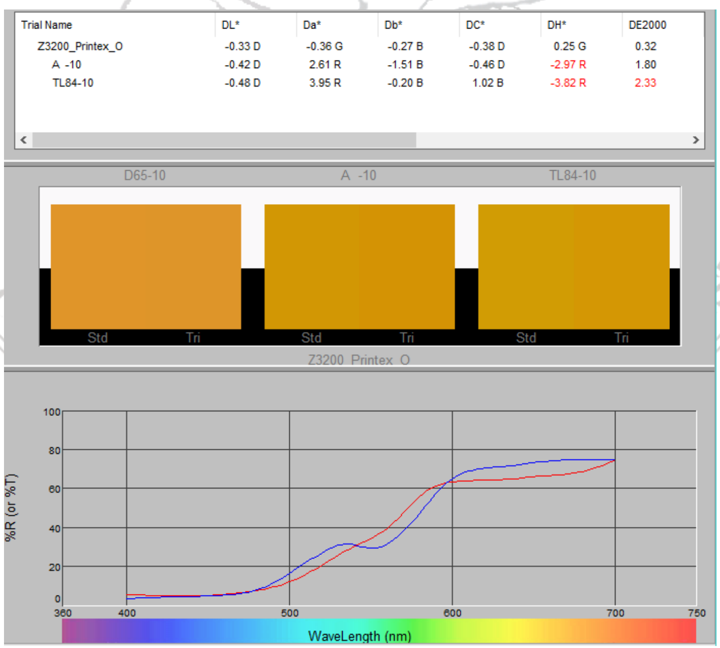

Fig. 12. ΔE^*_{00} and MI evaluation Color Standard/Reproduction Sample.

The solution is to generate a media dependent standard that will fulfil the approval criteria. This step involves the creation of color books, basically CIE L^*, C^* and h° incremental step variation of the master color standard reproduction. Using the same measurement protocol/device, the resulting variation samples shall be tested for best match and lowest MI value for the intended additional viewing conditions. Once such a sample identified, it can be added as a media dependent standard used in conjunction with the master color standard and used printing condition (Fig. 11).

Conclusions

(1). Based on different market requirements and expectations, any produced printing application using conventional and digital printing technologies is requiring different aim levels of the relevant set of parameters that should be stipulated to allow the printer to evaluate, control and test an entire print combination that will produce the print product and the print buyer to test the resulted print product against defined specifications and expectations.

(2). A typical print combination is responsible for the resulting print image quality and the assessment criteria and aims are not connected with the underlying printing technology, but defined by the requirements of the intended use case. Standardization in scope does not impose limitations on components such as substrates, inks or machinery. On the contrary, standardization allows for a manageable facilitation of a material and process diversity in terms of rigorous and consistent print quality. The practical use case results show that it is possible to closely match both the color accuracy for cross-industrial applications even for stringent requirements of lower than 1,0 ΔE^*_{00} not specific to graphic technology where the highest demanding tolerances for packaging applications are up to 2,5 ΔE^*_{00}. The current ICC technology and its colorimetrical match has limitations and requires additional steps in pure spectral match environment, but the incoming ICC max update is based on pure spectral workflow that will facilitate a much easier implementation of such requirements.

Acknowledgment

Fogra - How to Print the Expected Textile Project (2014).

Notations and/or **Abbreviations**

PDF/X-4 – Standard ISO 15930-7 data exchange format for the printing industry

M1 – Standard ISO 13655 measurement condition using CIE illuminant D50 spectral power distribution of the measurement source at the sample plane

P1 – Standard ISO 3664 viewing condition using CIE illuminant D50

CIE – Commission internationale de l'éclairage (French), the International Commission on Illumination

CIELAB – CIEL*a*b* 1976 color space

Fogra PSD – Process Standard Digital, an industrially orientated and standardized procedure for the creation of digital print products

SPI/SCI – Specular Port Included/Specular Component Included measurement specific to d:8° sphere optic geometry using closed black trap port

ICC – The International Color Consortium was established in 1993 for the purpose of creating, promoting and encouraging the standardization and evolution of an open, vendor-neutral, cross-platform color management system architecture and components.

R E F E R E N C E S

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